91602
new 82-10

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

ontario hydro
research division

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research If
Reproduced in Whole or in Part

NORTHERN CLIMATE HEAT PUMP FIELD EVALUATION

Report No 88-197-K

S. Yap
Engineer
Utilization Section
Electrical Research Department

ABSTRACT

Preliminary field data and related analysis for two prototype Northern Climate Heat Pump installations in Ontario are presented here. Heating system seasonal coefficients of performance of 2.07 and 2.15 were calculated for heat pump plus back-up at the Newmarket and Barrie test sites respectively. This represents the highest seasonal COP of any air-source heat pump ever measured by Ontario Hydro operating under central Ontario conditions. The prototype is expected to reduce the yearly heating bill by 55% for an "average" electrically heated home in Toronto. This heating cost would be about 10% less than heating with a high efficiency condensing gas furnace at current energy prices. The prototype could also form the basis of an add-on heat pump system in which back-up heating would be provided by oil or some other fuel.

job	file	date	report no.
12-587-011	814.344	December 20, 1988	88-197-K

ontario hydro

Research Division
800 Kipling Avenue, Toronto, Ontario, Canada M8Z 5S4

MEMORANDUM

DISTRIBUTION

December 12, 1988

File: 814.344(P)

Ontario Hydro Research Division Report No 88-197-K
Northern Climate Heat Pump Field Evaluation

Two CEA prototype Northern Climate Heat Pump field installations are described and evaluated in the attached Research Division Report (No 88-197-K). The heating seasonal efficiencies observed on these systems were 15 to 20% higher than any other air-source heat pump installation ever measured by Ontario Hydro. Even more importantly, these heat pumps significantly reduced heating demands during the cold temperatures prevailing at the time of the winter peak.

The CEA prototype heat pumps embody technology that gives them superior low-temperature performance compared to other commercially-available heat pumps. That this performance is achieved without radically different or expensive design features should interest industries committed to producing heat pumps for cold climates. This improved performance under Ontario winter conditions means that a customer's electric resistance energy bill could be cut by 55%, thus achieving a cost of heating that is still 10% lower than having a condensing gas furnace. More important for utilities is the 2 kW demand reduction that can be achieved by this heat pump even during peak times. In theory, this demand-reduction could be pushed to approximately 4 kW by altering the traditional sizing guidelines for installing air-source heat pumps.

The Canadian Electrical Association has agreed to co-fund plans to test improved electronics and a new expansion valve for their heat pump. We will keep you informed of our progress.

A.F. Baljet
Manager
Electrical Research Department
(Ext 0+405+6513)

D. Young:djy
(Ext 0+405+6815)

Attach.

Telephone (416) 231-4111 Telex No.: 06-984706 Facsimile (416) 231-9679

89-04817/

ontario hydro
research division

To Dr. D. Mills
Director of Research

NORTHERN CLIMATE HEAT PUMP FIELD EVALUATION

INTRODUCTION

To enable customers to make informed choices from the many home heating options available, they need information on seasonal efficiency and performance gathered under realistic or actual operating conditions. Well documented information is seldom available due to the difficulty, time and expense involved in carrying out actual field evaluations. However, as part of an ongoing program to provide benchmark seasonal efficiency measurements of various heat pumps, two prototype northern climate heat pumps, originally developed under contract with the Canadian Electrical Association (CEA), were installed and monitored in two Ontario homes. Data analyzed for this report covers the period from February 1986 to April 1987.

FIELD SITES

The Newmarket residence is a 2-storey structure, approximately 2000 sq. ft. with a measured heat loss of 8kW at -20°C outdoor air temperature. The Barrie residence is a well-insulated bungalow, approximately 2000 sq. ft., with a measured heat loss of 6.4kW at -20°C. The field installations were carried out by Ontario Hydro personnel in the fall of 1985. The CEA prototype heat pump replaced a conventional gas furnace at the Newmarket site and an electric resistance heating system at the Barrie site. Details of the heat pump are in Appendix A.

MEASUREMENT TECHNIQUES

The method used to measure performance under actual operating conditions over the entire heating season involved the operation of the heat pump (compressor and any necessary back-up heat) and electric resistance heaters on alternate days. This test method, referred to as the "Alternate Day Test" is simple and accurate and does not require extensive calibration. To gain more operating data, the test cycle was later changed to four consecutive days of heat pump operation followed by two consecutive days of electric resistance heating. A spot-check on steady-state performance was obtained by comparing the temperature rises across the heating system resulting from the electric heaters only and the heat pump (without back-up). Details of both test methods are given in Appendix B.

DATA ANALYSIS

The data presented here was collected over a two month period in the 1985-86 heating season and over a seven month period in the 1986-87 heating season for the Newmarket and Barrie test sites respectively. At regular intervals, homeowners were expected to record a set of readings from a monitoring package on data sheets which were provided for them. Completed data sheets were returned to Ontario Hydro on a monthly basis. This information was then transferred to spreadsheets for detailed analysis.

Average demand-versus-outdoor-temperature profiles were determined separately for both the electric resistance system and the all-electric heat pump system (compressor plus back-up heat). The demand profile for the calibrating electric resistance system can be taken as a surrogate for the actual heating system load of the structure since resistance heating is 100% efficient. Demand curves were then scaled to represent an "average" Toronto house that would consume 21000 kWh/year in electric resistance heat. Details are in Appendix C.

Using temperature bin analysis, heating seasonal efficiencies were calculated for the actual test sites and for an assumed Toronto location. This analysis involves dividing the temperature scale into a convenient number of temperature bins, multiplying the appropriate observed load at that temperature by the hours in that bin, and summing the resulting energies. Separate sums were produced for the electric resistance system and heat pump system total energies. The seasonal performance of the heat pump in each house was calculated by dividing the year's total electric resistance heating energy by the total heat pump system energy that would have been used for that same year. The results are summarized in Appendix D.

Using current energy prices, the yearly heating cost of the CEA prototype and three other heating systems were estimated for the "average" Toronto house. This analysis, carried out in Appendix E, compares the heating cost of the CEA prototype, electric furnace, conventional gas furnace and high efficiency gas furnace.

FIELD EXPERIENCES

In addition to determining the seasonal efficiency under actual operating conditions, the field test also served another purpose. Faults in the heat pump hardware and software were identified and resolved. These field experiences are described in Appendix F. Appendix G and H contain helpful field-installation tips and operational checks for the CEA prototype heat pump.

RESULTS

1. The actual house-heating demand and heat pump system demand profiles for the two field sites are given in Figures 1 and 2.

2. Heating seasonal efficiencies of 2.07 and 2.15 were calculated for the Newmarket and Barrie field sites respectively (Table 1). This is 15% to 19% higher than commercially-available air-source heat pumps with electric back-up.

3. Demand profiles for the "average" Toronto house (which would consume 21000 kWh/year in electric resistance heat) are given in Figure 3. This provides a useful base for comparing demand and energy consumption of different heating systems.

4. Temperature bin analysis using Toronto weather data/1/, yielded a seasonal efficiency of 2.2 for the "average" house. Details of this analysis are in Appendix C.

5. The CEA prototype had relatively low balance points in the two houses (Figures 1 and 2). This was not so much because the heat pumps were oversized for the houses, but rather because the CEA heat pump maintains its output and efficiency to much lower temperatures than conventional equipment/2/. (Each heat pump was a nominal "2-1/2 ton" capacity machine, sufficient for the house cooling loads and typical of the average size machine sold in Ontario.) This low balance point feature means that the CEA heat pump can significantly reduce electricity demands even at temperatures below -15°C (see Figure 3).

6. The CEA prototype is 10% less expensive to operate than a high efficiency gas furnace, at today's energy prices in Toronto. The CEA prototype saves 55% compared to an electric furnace (Figure 4).

7. The manufacturer's pressure-initiated demand defrost control was found to be unreliable for field operations and was replaced with a microprocessor-based defrost control.

8. The indoor unit is somewhat bulky and awkward to move downstairs in its present form. If future designs separated the compressor and fan compartments, retrofit installations would be easier.

9. Heat pump lock-outs in the first few months of operation were eventually traced to a conflict between the defrost control and the microprocessor algorithm. The software was later replaced by the manufacturer.

10. Another software shortcoming resulted in poor refrigerant control at some outdoor temperatures. The heat pump has difficulty in coming out of the start-up mode/2/. An in-house circuit was developed to bolster the start-up performance of the unit (Appendix F).

Table 1 Heat Pump Seasonal Efficiencies

	Estimated Annual Heating Energy Consumption with an Electric Furnace (kWh)	Estimated Annual Heating Energy Consumption with the Heat Pump System (kWh)	SCOP*
Newmarket	16373.52	7893.66	2.07
Barrie	12277.73	5705.09	2.15

* Seasonal Coefficient of Performance calculations in Appendix D

CONCLUSIONS

1. The seasonal efficiency of the CEA prototype heat pump would be 2.2 for an average house in Toronto. This is about 22% higher than commercially-available air-source units with electric back-up.

2. The CEA prototype greatly lowers energy consumption for heating purposes in cold climates. Savings of 55% can be expected compared to a Toronto home heated with an electric furnace. The prototype is also 10% less expensive to operate than a high efficiency condensing gas furnace at current energy prices.

3. The demand profiles provide utilities and the public with well documented performance information. This information can be used to assess electricity demand and energy consumption characteristics in any area. Ontario Hydro can use these field results to shape heat pump development and marketing programs.

4. The CEA prototype has an attractive load profile from both the customer's and utility's point of view. Lower demand means reduced heating costs for the consumer and lower winter peak loads for the utility.

5. Problems, including an unreliable defrost sensor and a poor microprocessor control algorithm, indicate further product refinements are necessary. However, the changes required are relatively minor and easily implemented.

6. Demand savings are expected to be proportionally greater in homes equipped with larger capacity versions of this CEA heat pump, even at temperatures below -20°C.

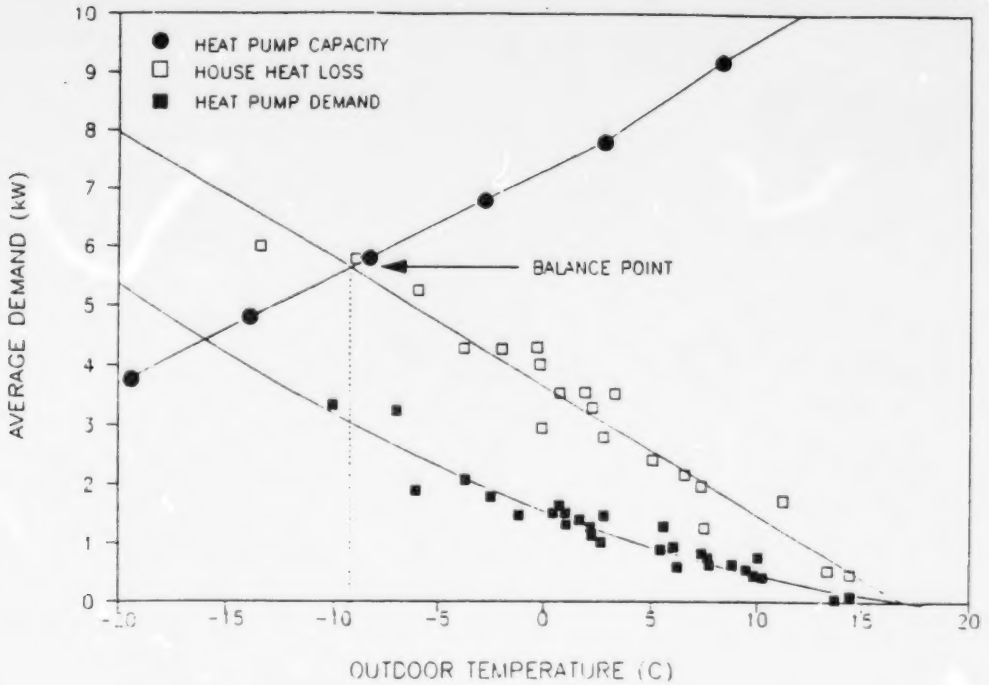

FIGURE 1: NEWMARKET HEAT PUMP FIELD DATA
85-86 HEATING SEASON

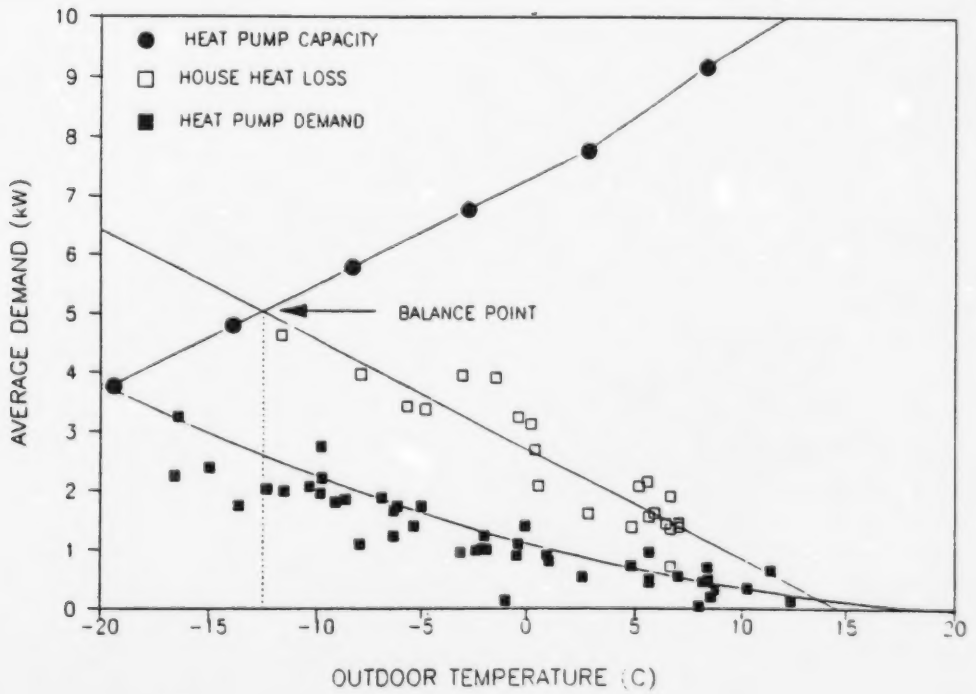

FIGURE 2: BARRIE HEAT PUMP FIELD DATA
86-87 HEATING SEASON

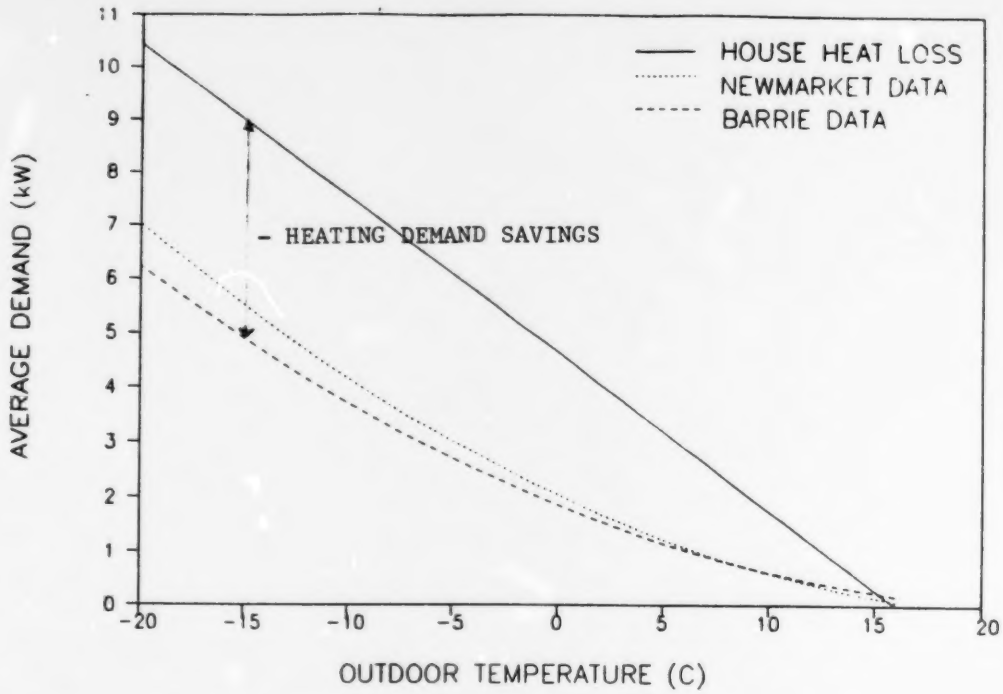

FIGURE 3: FIELD DATA FOR STANDARD HOUSE
21000 kWh/YR ELECTRIC RESISTANCE HEAT

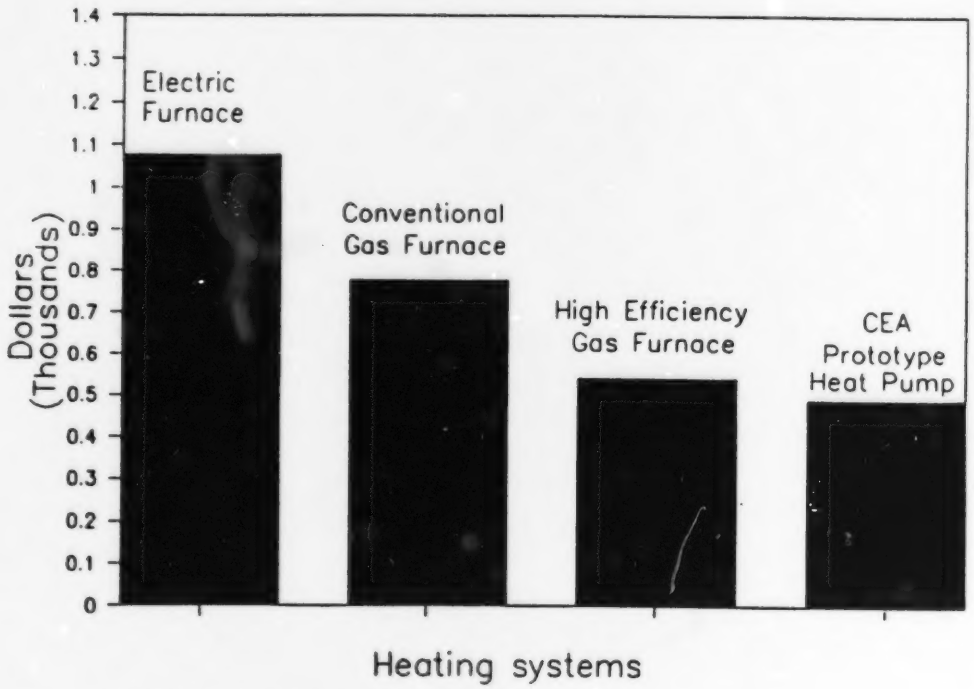

FIGURE 4: YEARLY HEATING COST
"AVERAGE" HOUSE IN TORONTO

RECOMMENDATIONS

The technology embodied in the CEA prototype heat pump is available and ready to be transferred to industries committed to producing heat pumps for cold climates. To make the product even more attractive, further work should be carried out to refine the heat pump electronics, expansion valve and service diagnostics.

Approved by:

A.F. Baljet
Manager
Electrical Research Dept

Submitted by:

S. Yap
Engineer
Utilization Section

Reviewed by:

D.J. Young
Unit Head - Thermal Systems
Utilization Section

SY:ib

REFERENCES

1. Porfido, F.S., "Toronto Weather Data", Ontario Hydro Research Division Report No 82-397-K, (December 1982).

2. Yap, S., "Northern Climate Heat Pump Laboratory Evaluation", Ontario Hydro Research Division Report No 87-177-K.

3. Young, D.J. and Lange, H.F., "Optimization and Evaluation of a Northern Climate Residential Air-Source Heat Pump", Canadian Electrical Association report #76-12 by Ontario Hydro Research Division, October 1980.

4. Young, D.J., "Three Years of Measured Performance for Two Dealer-Installed Add-on Heat Pumps", International Dual Energy Heating Symposium, Toronto, (October 17-18, 1983).

5. "Monthly Rates and Comparative Bills, Ontario Hydro and Associated Municipal Utilities", (July 1987).

6. Denton, D., "Commercialization of an Improved Residential Air-Source Heat Pump", CEA Contract 007U207 Draft Final Report, (May 1986).

APPENDIX A

HEAT PUMP DESCRIPTION

General

The prototype heat pump is a residential split-system, air-source design with a nominal heating capacity of 9 kW (2.5 ton). For added efficiency and easy service access, the compressor is located indoors. The airflow through the large indoor coil is handled with a variable-speed 1/4 hp direct-drive blower. Refrigerant control is carried out by a microprocessor-controlled thermal-electric expansion valve which forms the heart of the system. The microprocessor board receives input from the discharge line thermostat, room thermostat, defrost control and receiver level thermistor, and controls the operation of the compressor, reversing valve, bypass valve, and expansion valve. The microprocessor board has three system status lights to indicate the condition of the heat pump system. A failure of the microprocessor board results in the loss of proper heat pump operation. However, a level of comfort can still be maintained as the microprocessor is not necessary to operate the back-up electric heaters. A heat pump schematic is presented in Figure 5.

The heat pump is factory-charged with R-22 refrigerant. The indoor and outdoor units contain 3.6 kg (8 lbs) and 0.9 kg (2 lbs) of charge respectively. Precharged refrigerant tubing is also supplied with the heat pump. The fittings are "one shot" type and care is required before the final tightening and puncturing of the diaphragm.

Field installations were carried out by Ontario Hydro personnel in the fall of 1985. The heat pump prototype replaced the existing furnace and became the heating/cooling source at each test site.

Improvements Embodied in the Heat Pump

This section will list a few of the improvements embodied in the heat pump.

1) The compressor is located indoors thus avoiding the need for crankcase heating and allowing shell and discharge piping losses to contribute to useful heat pump output. The indoor location also improves the service and maintenance environment.

2) The unit uses demand defrost. However, the method of defrost initiation differs from the design recommended in the original CEA report/3/ (sensing an increase in outdoor fan current). The present prototype utilizes a defrost control unit that is preset to defrost the outdoor coil whenever these conditions occur simultaneously:

   - outdoor coil temperature below -2.8°C ±1.7°C (27°F ± 3°F)

   - outdoor coil static pressure drop greater than 50 ± 1.5 Pa (0.20" ± .03" WC)

- after an initiation inhibit period of 20 ± 2 minutes has elapsed since the previous defrost terminated.

Defrost is terminated either when the coil temperature reaches 12.7°C ± 2.1°C (55°F ± 5°F), or after a 10 ±1 minute duration, whichever occurs first.

3) A thermal electric expansion valve, an accumulator heat exchanger, and a special receiver work together to provide optimal refrigerant control. Receiver level control ensures that the outdoor evaporator remains flooded and a fixed portion of the condenser is devoted to subcooling over the entire range of operating conditions. A thermistor senses the receiver level and through the help of the microprocessor delivers a signal to the expansion valve. Should the receiver level be high, the expansion device responds by opening, thus permitting the receiver level to fall. In addition to providing optimal flow conditions, the voltage setting for the expansion valve position can be stored in memory for fast system recovery after defrost or off cycle.

4) The heat pump utilizes an accumulator heat exchanger which performs the following useful functions.

   - it enhances transient performance during start-ups and following defrost cycles

   - it allows for oscillations in the expansion valve opening operations without starving the evaporator

   - it helps to ensure that all of the evaporator circuits remain flooded.

5) Coil areas of both the indoor and outdoor unit are large and at the higher end of normal practice. This results in greater heat transferred by the system.

6) A defrost bypass valve, located across the cooling mode expansion device (capillary tubes), helps prevent oil foaming in the compressor sump and maintain a higher rate of mass flow and heat delivery to the outdoor coil. This reduces the defrost cycle time compared to defrosts where only the cooling mode expansion device is used.

The above improvements all work to provide a higher performance heat pump.

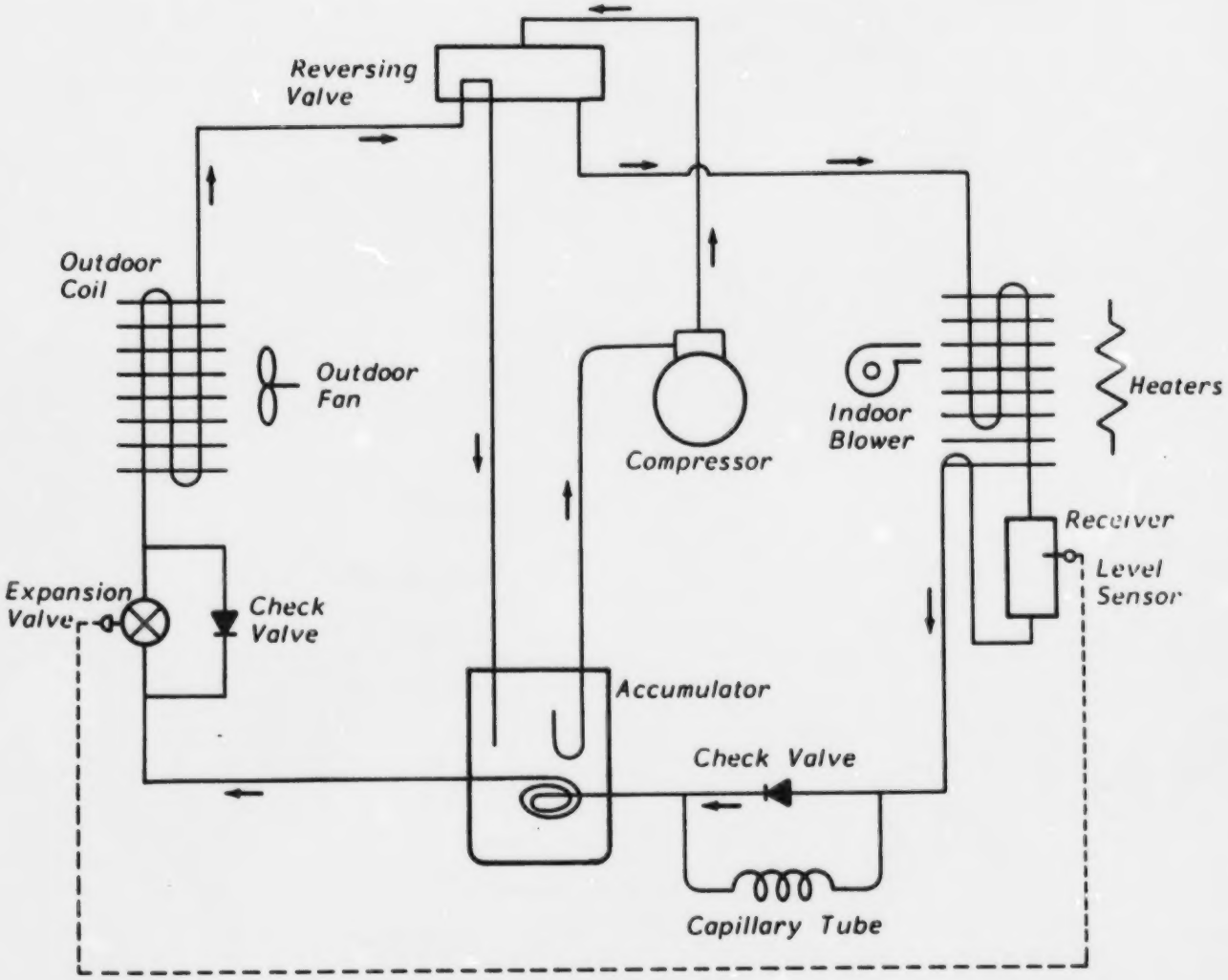

FIGURE 5

HEAT PUMP BLOCK DIAGRAM
(HEATING MODE)

APPENDIX B

MEASUREMENT TECHNIQUES

Heating system seasonal efficiency can be measured in a number of ways. Most methods used compare, in some way, the output of the unknown heating system to an equivalent electric resistance heating system. This comparison is based on the ease of measuring the electric input to an electric resistance heater and the assumption that electric heaters are 100% efficient. Two measurement techniques were used in the CEA prototype heat pump field trial.

ALTERNATE DAY TEST

The "Alternate Day" test method involves the operation of the unknown heating system and an equivalent electric resistance heating system on alternate days over the entire heating season. By doing this, the two systems operate under similar weather conditions for the same length of time. At the end of the heating season, the seasonal efficiency is determined simply by dividing the electric furnace energy consumption by the heat pump energy consumption. Unfortunately, this simple approach can be complicated by disruptions in the test. Some repairs and maintenance were necessary in the course of the field trial. During such periods, the heat pump was shut down and the heating requirements were met solely by the electric heaters. Subsequently, the seasonal efficiency could no longer be determined in the manner above. A temperature bin analysis based on daily temperature and energy measurements became necessary to calculate the SCOP (Seasonal Coefficient of Performance) (Appendix C).

The "Alternate Day" test was operated with a monitoring package. This package consisted of two kilowatt-hour meters, 2 electromechanical counters, 3 electromechanical timers, a 24-hour switch-over timer and a latching relay. These items were mounted on a plywood base and installed beside the heat pump.

The 24-hour timer performed the alternate day switching operation through the latching relay. The two kilowatt-hour meters recorded the energy consumption of the heating system in the two modes, heat pump (plus back-up if necessary) and electric furnace only. The mechanical counters registered the following run times and cycles: heat pump elapsed time, heat pump cycles, defrost elapsed time, defrost cycles and auxiliary heater elapsed time.

The "Alternate Day" test format was changed in 1986-87 heating season to increase the heat pump operating hours. The heat pump was set up to run for 4 consecutive days followed by 2 consecutive days of electric resistance heating operation. The analysis of such unequal alternate periods was also performed using the bin method (Appendix C).

TEMPERATURE RISE METHOD

This method involved the comparison of the temperature rise across the heating system resulting from a known calibrating heating element and the unknown heating system. This simple technique required two temperature measurements and two power readings. It was used to spot check the steady-state performance of the units during service calls.

The procedure is outlined below:

1. Record outdoor air temperature.
2. Remove power to the heat pump and disconnect second-stage heater.
3. Reapply power and initiate call for heat in the heat pump mode.
4. Allow system temperatures to stabilize.
5. Record inlet air and discharge air temperature. Call this temperature difference T_1.
6. Using a stop watch, record the time taken in seconds for 10 disc rotations of the heat pump kilowatt-hour meter. Call this time t_1.
7. Shut off the heat pump, disconnect power and reconnect the second stage heater.
8. Reapply power and turn on the electric resistance (second stage) heaters only.
9. Allow system temperature to stabilize.
10. Record temperature difference between inlet and discharge air. Call this T_2.
11. Using a stop watch, record time taken in seconds for 10 disc rotations of the electric furnace kilowatt-hour meter. Let this be t_2.

Carry out the following calculations to determine the COP.

Heat pump temperature rise = T_1
Time for 10 disc rotations = t_1

Electric Furnace temperature rise = T_2
Time for 10 disc rotations = t_2

i) Calculate Heat pump power input P_1 using formula below.

$$P = \frac{DR}{t} \times Kh \times 3600 \quad \text{(Watts)}$$

Where DR - # of disc rotations in specified time (rev)
Kh - meter constant (Wh/rev)
t - time in seconds for disc rotation
3600 - correct seconds to hours (s/h)

ii) Calculate electric furnace power input P_2 using above formula.

iii) Calculate electric furnace thermal output

Assume: electric heater are 100% efficient
ie power input = thermal output = P_2

iv) Calculate Heat pump thermal Output P_3

$$P_3 = \frac{T_1 \times P_2}{T_2}$$

v) Calculate Coefficient of Performance (COP)

$$COP = \frac{\text{Heat pump thermal output}}{\text{Heat pump electrical input}}$$

$$COP = \frac{P_3}{P_1}$$

Example

Barrie field test site

Heat Pump mode

Discharge Air temperature 38°C
Indoor Air temperature 20°C

Difference T_1 = 15°C

Time for 10 disc rotations
t_1 = 71.42 sec

Heat pump electrical input P_1

$$P_1 = \frac{10 \times 6 \times 36000}{71.42} = 3024 \text{ Watts}$$

Electric Resistance Heating mode

Discharge Air temperature 36.5°C
Indoor Air temperature 23.0°C

Difference T_2 = 13.5°C

Time for 10 disc rotations
t_2 = 26.29 sec

Electric resistance heaters power input

$$P_2 = \frac{10 \times 6 \times 3600}{26.29} = 8216 \text{ Watts}$$

Heat pump thermal output $P_3 = \frac{T_1 \times P_2}{T_2}$

$$= \frac{15 \times 8216}{13.5}$$

P_3 = 9128 Watts

$$COP = \frac{P_3}{P_1} = \frac{9128 \text{ W}}{3024 \text{ W}} = 3 \quad @ 5.6°C \text{ outdoor air temperature}$$

APPENDIX C

DATA ANALYSIS

DATA COLLECTION

A monitoring package containing two kilowatt-hour meters, five digital counters and a switch-over timer was installed along with the heat pump. The timer performed the switching function for the "Alternate Day" test format and the kilowatt-hour meters recorded the two energy quantities. The counters recorded cycles and run times of the compressor, defrost and back-up heaters.

Data sheets were provided and the home owner was expected to take a set of readings from the monitoring package at regular intervals. The suggested minimum reading frequency was twice a week on consecutive days. The home owners at these two sites were extremely helpful in providing additional data. Problems encountered in the field occasionally disrupted data collection. The data presented in this report was taken over a two month period between February 28 and May 2, 1986 for the Newmarket site and over a seven month period between October 8, 1986 and April 13, 1987 for the Barrie field site.

DATA ANALYSIS

Completed data sheets were returned to Ontario Hydro on a monthly basis. This information was transferred to spreadsheets for detailed analysis. Two spreadsheets were created for each field site. One contained information from heat pump days only and the other contained information from electric furnace days only. The required outdoor temperature information was taken from local weather stations.

The primary objective of this field test was to determine the seasonal efficiency of the CEA prototype heat pump. For this, the demand profiles of the heat pump (plus back-up heat) and electric furnace were required. The average heat pump system and electric resistance system demands were calculated by dividing the respective energy consumption by the corresponding total elapsed time between readings. The demand profiles were obtained by plotting average demand versus outdoor temperature and getting the best curve fit through these data points. A linear regression was used to fit the data points for the electric resistance system data, and a quadratic regression was used to fit the heat pump system data.

A temperature bin analysis was then performed to estimate the yearly energy consumption of the two heating systems: heat pump (plus back-up heating) and electric resistance. The temperature scale was divided into 3°C temperature bins. The load at each bin center was determined from the demand profiles. The yearly number of hours at the bin center temperature was taken from the temperature frequency table in "Toronto Weather Data" OHRD report #82-397-K/1/. The load and the number of hours in each bin were multiplied to give the energy consumption for that particular bin. The summation of these values yielded the total estimated energy consumption for the heating system.

The seasonal COP for Toronto was determined by dividing the total electric furnace estimated energy consumption by the total heat pump estimated energy consumption. The heat pump results are summarized in Appendix D.

STANDARDIZING FIELD DATA

The demand profiles in Figure 1 and 2 are specific to the two field sites. For greater flexibility in data analysis, these demand profiles were scaled for an "average" 1600 sq. ft. Toronto house which would require 21,000 kWh/year in electric resistance heat.

Data was scaled as follows:

1. Winter period was assumed to be between October and March inclusive

2. Total number of degree-hours in Toronto between October and March is 72427 degree-hours using a base of 16°C/1/.

3. Scaling factor f (slope of the heating system load line), for a 21,000 kWh/year house

$$f = \frac{21{,}000 \text{ kWh}}{72427 \text{ deg-hour}}$$

$$f = 0.2899 \text{ kWh/deg-hour} = 0.2899 \text{ kW/deg}$$

4. Scaled house load for the "average" house at the different outdoor temperature is

   Scaled house load = abs (16 - outdoor temperature) x 0.2899 kWh/deg

5. Heat pump demand for the "average" house at different outdoor temperatures is

$$\text{Scaled heat pump demand} = \text{Heat pump field data} \times \frac{\text{Scaled house load @ -20°C}}{\text{Actual house load @ -20°C}}$$

To obtain accurate data, the minimum reading frequency should be increased to get additional data points. Regular service calls are required to ensure the proper operation of the heat pump and to spot problems.

APPENDIX D

HEAT PUMP RESULTS

HEATING SYSTEM PERFORMANCE

The electric resistance system and heat pump system demand profiles for the Newmarket test site are given in Figure 1. The electric resistance heater operation represents the house heat loss. At -20°C outdoor temperature, the house heat loss is 8kw. The intersection of this line with the heat pump capacity curve gives the system's balance point of -9°C. The balance point is the outdoor temperature at which the heat pump output exactly matches the heating requirement of the building. When the outdoor temperature falls below the balance point, some supplementary heating is required to maintain the indoor conditions.

Figure 2 shows the electric furnace and heat pump demand profiles for the Barrie field site. This well-insulated structure has a heat loss of 6.4 kW at -20°C outdoor air temperature. The system balance point is -12.5°C.

Seasonal efficiencies of the heat pump system for the two sites were determined using temperature bin analysis (Appendix C). The seasonal coefficients of performance (SCOPS) were 2.07. and 2.15 for the Newmarket and Barrie test sites respectively using normalized Toronto weather data. The results are tabulated in Table 2.

STANDARD DATA

The demand profiles in Figures 1 and 2 are specific to the two field sites. To make a practical comparison, the demand profiles were standardized for an "average" Toronto house which would require 21,000 kWh/year of electric resistance heat.

To estimate the loads for this "average" house in Toronto, scaling factors were determined from winter (October to March inclusive) temperature date/1/. Figure 3 shows the demand profiles for the "average" house using the underlying Newmarket and Barrie demand profiles. Temperature bin analysis yielded SCOP of 2.02 and 2.26 for the Newmarket and Barrie sites respectively. The results are tabulated in Table 3. The superior performance of the Barrie heat pump can be attributed to two factors:

1. The installation of a special electronic circuit to improve start-up mode performance.

2. Reduced auxiliary heater consumption due to lower house balance point.

TABLE 2

HEAT PUMP BIN PERFORMANCE DATA
UNDER AVERAGE "TORONTO" WEATHER

	NEWMARKET FIELD DATA							BARRIE FIELD DATA				
OUTDOOR TEMP (C)	BIN CENTRE (C)	db TEMP FREQ # HR/YR (HR)	HOUSE LOAD (kW)	HEAT PUMP DEMAND (kW)	SYSTEM TOTAL FIELD COP	HEAT PUMP ENERGY (kWh)	ELEC FURN ENERGY (kWh)	HOUSE LOAD (kW)	HEAT PUMP DEMAND (kW)	FIELD COP	HEAT PUMP ENERGY (kWh)	ELEC FURN ENERGY (kWh)
16.00			0.19	0.08	2.28			0.00	0.00	0.00		
15.00	15.00	120.00	0.40	0.13	3.00	16	48	0.00	0.00	0.00	17	0
14.00			0.62	0.19	3.21			0.11	0.19	0.57		
13.00			0.83	0.26	3.26			0.29	0.23	1.28		
12.00	12.00	194.00	1.05	0.32	3.23	63	203	0.48	0.28	1.74	53	92
11.00			1.27	0.40	3.17			0.66	0.33	2.04		
10.00			1.48	0.48	3.09			0.85	0.38	2.24		
9.00	9.00	283.00	1.70	0.56	3.01	159	480	1.04	0.44	2.36	124	293
8.00			1.91	0.65	2.92			1.22	0.50	2.44		
7.00			2.13	0.75	2.84			1.41	0.57	2.49		
6.00	6.00	367.00	2.35	0.85	2.75	312	861	1.59	0.64	2.50	233	585
5.00			2.56	0.96	2.67			1.78	0.71	2.50		
4.00			2.78	1.07	2.59			1.97	0.79	2.49		
3.00	3.00	603.00	3.00	1.19	2.52	716	1806	2.15	0.87	2.47	524	1297
2.00			3.21	1.31	2.45			2.34	0.96	2.44		
1.00			3.43	1.44	2.38			2.52	1.05	2.41		
0.00	0.00	833.00	3.64	1.57	2.32	1311	3035	2.71	1.14	2.38	949	2257
-1.00			3.86	1.71	2.25			2.90	1.24	2.34		
-2.00			4.08	1.86	2.19			3.08	1.34	2.30		
-3.00	-3.00	615.00	4.29	2.01	2.14	1234	2640	3.27	1.44	2.26	888	2009
-4.00			4.51	2.16	2.08			3.45	1.55	2.22		
-5.00			4.73	2.32	2.03			3.64	1.67	2.18		
-6.00	-6.00	447.00	4.94	2.49	1.98	1113	2208	3.83	1.78	2.14	797	1710
-7.00			5.16	2.66	1.94			4.01	1.90	2.11		
-8.00			5.37	2.84	1.89			4.20	2.03	2.07		
-9.00	-9.00	338.00	5.59	3.02	1.85	1021	1889	4.38	2.16	2.03	729	1481
-10.00			5.81	3.21	1.81			4.57	2.29	1.99		
-11.00			6.02	3.40	1.77			4.76	2.43	1.96		
-12.00	-12.00	234.00	6.24	3.60	1.73	842	1459	4.94	2.57	1.92	601	1156
-13.00			6.45	3.80	1.70			5.13	2.71	1.89		
-14.00			6.67	4.01	1.66			5.31	2.86	1.86		
-15.00	-15.00	137.00	6.89	4.23	1.63	579	943	5.50	3.01	1.82	413	753
-16.00			7.10	4.45	1.60			5.69	3.17	1.79		
-17.00			7.32	4.67	1.57			5.87	3.33	1.76		
-18.00	-18.00	77.00	7.54	4.91	1.54	377	580	6.06	3.50	1.73	269	466
-19.00			7.75	5.14	1.51			6.24	3.66	1.70		
-20.00	-21.00	27.00	7.97	5.38	1.48	145	215	6.43	3.84	1.68	103	173
					TOTALS	7893	16373			TOTALS	5705	12277
					SCOP =		2.07			SCOP =		2.15

TABLE 3
FIELD DATA SCALED FOR "AVERAGE" HOUSE

	NEWMARKET DATA FOR "AVERAGE" HOUSE*						BARRIE DATA FOR "AVERAGE" HOUSE*		
OUTDOOR TEMP (C)	BIN CENTRE (C)	db TEMP FREQ # HR/YR (HR)	"AVERAGE" HOUSE LOAD** (kW)	NEWMARKET HEAT PUMP IN AVG HOUSE (kW)	AVG HOUSE ELEC FURN ENERGY (kWh)	AVG HOUSE HEAT PUMP ENERGY (kWh)	BARRIE HEAT PUMP IN AVG HOUSE (kW)	AVG HOUSE ELEC FURN ENERGY (kWh)	AVG HOUSE HEAT PUMP ENERGY (kWh)
16.00			0.00	0.11			0.18		
15.00	15.00	120.00	0.29	0.18	34	21	0.24	34	28
14.00			0.58	0.25			0.30		
13.00			0.87	0.34			0.37		
12.00	12.00	194.00	1.16	0.43	224	82	0.45	224	86
11.00			1.45	0.52			0.53		
10.00			1.74	0.63			0.62		
9.00	9.00	283.00	2.03	0.74	574	209	0.71	574	201
8.00			2.32	0.86			0.81		
7.00			2.61	0.98			0.92		
6.00	6.00	367.00	2.90	1.12	1063	409	1.03	1063	379
5.00			3.19	1.26			1.15		
4.00			3.48	1.40			1.28		
3.00	3.00	603.00	3.77	1.56	2272	939	1.41	2272	852
2.00			4.06	1.72			1.55		
1.00			4.35	1.89			1.70		
0.00	0.00	833.00	4.64	2.06	3863	1717	1.85	3863	1541
-1.00			4.93	2.24			2.01		
-2.00			5.22	2.43			2.17		
-3.00	-3.00	615.00	5.51	2.63	3387	1617	2.34	3387	1441
-4.00			5.80	2.83			2.52		
-5.00			6.09	3.05			2.71		
-6.00	-6.00	447.00	6.38	3.26	2850	1458	2.90	2850	1294
-7.00			6.67	3.49			3.09		
-8.00			6.96	3.72			3.30		
-9.00	-9.00	338.00	7.25	3.96	2449	1337	3.51	2449	1184
-10.00			7.54	4.20			3.72		
-11.00			7.83	4.46			3.94		
-12.00	-12.00	234.00	8.12	4.72	1899	1103	4.17	1899	976
-13.00			8.41	4.99			4.41		
-14.00			8.70	5.26			4.65		
-15.00	-15.00	137.00	8.99	5.54	1231	759	4.90	1231	670
-16.00			9.28	5.83			5.15		
-17.00			9.57	6.13			5.41		
-18.00	-18.00	77.00	9.86	6.43	758	494	5.68	758	437
-19.00			10.15	6.74			5.95		
-20.00	-21.00	27.00	10.44	7.05	281	190	6.23	281	168
				TOTALS	20893	10342	TOTALS	2093	9263
				SCOP =	2.02		SCOP =		2.26

* "AVERAGE" HOUSE REQUIRES 21,000 kWH/YEAR IN ELECTRIC RESISTANCE HEAT

** BASED ON 16 DEG C BASE TEMPERATURE (DEG-HOUR = 7 WINTER - OCTOBER TO MARCH INCLUSIVE

SYSTEM OPERATING PARAMETERS

The readings provided additional information of interest that is summarized in Table 4. The accumulated heat pump operating hours are for only the fraction of the heating season documented earlier, but the data does reflect the behavior of the heat pump units.

Table 4 System Operating Parameters

Parameters	Newmarket 1985-86 (2 months)	Barrie 1986-87 (6 months)
Heat Pump Operating Hours	283	604
Number of Heat Pump Cycles	893	1186
Number of Defrost Cycles	172	294
Average Heat Pump On-time (Min)	19.05	30.38
Average Defrost Cycle Duration (Min)	4.06	4.05
Average Run Time per Defrost (Min)	98.9	123.4

The average heat pump on-times of 19.05 min and 30.58 min for Newmarket and Barrie are shorter than those observed in other field performance measurements of heat pumps/4/. This may reflect the fact that the heat pumps maintain their output as temperature falls, and as a result, cycle for shorter time periods. Average duration of a defrost cycle is approximately 4 minutes. This observation is reasonable and agrees with the observation in the previous report/4/.

SPOT COP MEASUREMENTS

During service calls, a simple technique was utilized to check the performance of the heat pumps. This method involved measuring temperature rise across the heat pump (no back-up heat) and comparing it to the temperature rise across the resistance heater elements only. Details of this procedure are given in Appendix B.

Steady-state spot COP readings taken during field visits to the Barrie and Newmarket sites yielded values of 3 and 2.7 at outdoor temperatures of 5.6°C (42°F) and 3.5°C (38.3°F) respectively. Corresponding steady-state laboratory values interpolated for the above temperatures yielded COP values of 3.05 and 2.94 respectively.

APPENDIX E

HEAT PUMP SAVINGS

In general, home owners do not readily understand COP and SCOP but they can relate to "after-tax income". In reality, this is the dollar savings achieved by reducing heating energy consumption.

A comparison of four heating systems is made in this appendix. They are: electric furnace, conventional gas furnace (60% efficient), high efficiency gas furnace (90% efficient) and CEA prototype heat pump. Yearly heating costs are estimated for the "average" house in Toronto that would consume 21,000 kwh/yr of electric resistance heat. The CEA prototype heat pump turned out to be the cheapest heating system of the four (Table 5).

Calculations were as follows:

Assume house heating requirement is 21,000 kWh/year.

1. Electric Furnace

End rate = 0.0513 $/kWh Reference - "Monthly rate and comparative bills" July 1987 /5/.

Yearly heating Cost = 21,000 kWh/year x 0.0513 $/kWh
= $1,077.30

2. 60% efficient Gas Furnace

House heating requirement is 21,000 kWh/year

Equivalent Gas required (@ 60% efficiency) = $\frac{21,000}{0.60}$ kWh
= 35,000 kWh(1.26×10^8 kJ)

Heating Value of Gas = 37,300 kJ/m^3

Required Gas Volume = $\frac{1.26 \times 10^8 \text{ kJ}}{37300 \text{ kJ/m}^3} = 3378 \text{ m}^3$

Gas rate = 0.230 $/m^3$

Yearly heating cost = $\frac{0.23\$}{m^3} \times 3378 \text{ m}^3$

= $776.94

3. 90% Efficient gas furnace

Equivalent Gas required $= \frac{21,000}{0.9}$ kWh = 23,333 kWh
or 8.4×10^7 kJ

Required Gas Volume $= \frac{8.4 \times 10^7}{37,300}$ kJ $= 2,252\ m^3$

Gas rate = $0.24\ \$/m^3$

Yearly heating cost $= \frac{0.24\$}{m^3} \times 2,252\ m^3$

$= \$540.48$

CEA Prototype Heat Pump

SCOP = 2.20
Heat Pump energy required $= \frac{21,000}{2.20}$ kWh = 9,545.45 kWh

Yearly heating cost $= 0.0513\ \$/kWh \times 9,545.45\ kWh$
$= \$489.68$

Table 5 Heat Pump Savings for "Average" House

Heating System	Yearly Heating Cost	Savings with CEA Prototype
Electric Furnace	$1,077.30	54.5%
60% Efficient Gas Furnace	$ 776.94	37.0%
90% Efficient Gas Furnace	$ 540.48	9.4%
CEA Prototype Heat Pump	$ 489.68	---

Various costs of operation were also calculated by the heat pump manufacturer/6/. These were based on heating a 14,880 kWh/yr house in Toronto that has a heating load of 200 watt/deg C below 15°C. A cyclic performance degradation model was included to make the numbers more realistic. The operating cost of the CEA prototype was estimated to be 20% lower than that of a condensing gas furnace in that particular house.

APPENDIX F

FIELD EXPERIENCES

In addition to determining the seasonal efficiency under actual operating conditions, the field test also served a secondary purpose. Problem areas were identified so as to avoid customer dissatisfaction with production units.

The indoor unit is somewhat bulky and awkward to move down a set of stairs and into the basement. A separate compressor compartment and indoor blower unit in future designs would make retrofit installation easier.

The prototype units suffered from "housekeeping" defects that are best corrected by carrying out a full operational check after the heat pump goes into service. Appendix H contains the operational check. Defects included incorrect wiring of the indoor blower (reverse rotation), outdoor fan (wrong speed selection), and defrost sensor (N.O/N.C. contact mix-up)/2/.

Problems were also encountered during heat pump operation. The heat pump experienced difficulty in coming out of the start-up mode. There were "mysterious" lock-outs and the defrost sensor proved to be unreliable.

As noted in the laboratory evaluation/2/, the heat pump has two modes of operation, initial and normal. The initial mode is set after on/off cycle or defrost cycle. The normal program mode runs only after the receiver goes through one complete refrigerant level transition (empty-full-empty cycle). However, this algorithm is successful only through a limited range of outdoor temperatures (between 8°C and -14°C). Outside of this temperature range, the heat pump has difficulty in coming out of the initial program mode. This resulted in poor refrigerant control and lower output and efficiency.

An in-house circuit, consisting mainly of logic gates and timers, was developed to bolster the heat pump start-up mode control. This circuit monitors four component conditions: Compressor on/off, Receiver empty/full, Accumulator empty/full, and Defrost on/off. Depending on the status of these four inputs, the circuit logic initiates a sequence of actions to force the receiver level through one complete empty-full-empty cycle. Once this action is complete, control is passed back to the main microprocessor board. This circuit was installed in the Barrie test site and results indicate an improvement in the overall performance.

A lock-out normally occurs when the microprocessor fails. In the first few months of operation, the heat pump frequently locked out even though the microprocessor did not fail. The cause of these "mysterious" lock-outs was eventually traced to the defrost control. This particular control had a built-in six hour real-time call for defrost which initiated defrost regardless of whether the heat pump was on or not! A call for heat during these phantom defrosts would be interpreted by the microprocessor algorithm as a conflict between heating and cooling mode. Subsequently, the microprocessor would lock-out. The software was later changed by the manufacturer/6/.

The reliability of the defrost control was also suspect. One control did fail and had to be replaced with a microprocessor-based defrost control. The new controls provided effective defrosts and should be considered in future designs.

The heat pump, when operating, worked extremely well but the field problems proved to be annoying. Tests were interrupted by the need for maintenance and repairs. It appears that further refinement is required before the product is market ready. However, the technology embodied in the CEA prototype is ready to be transferred to industries committed to producing heat pumps for cold climates.

APPENDIX G

TIPS FOR INSTALLING THE KEEPRITE/CEA COLD CLIMATE HEAT PUMP

Dave Young, Ontario Hydro

This set of instructions is not meant to replace the Installation and Service Manual packed with the heat pump. Most details on the installation (such as how to install the refrigerant line sets using plenty of refrigerant oil on the threads and "O" rings) are in the Manual. This memo is a list of hints I found useful when installing our units in the field.

Unpacking:

1. The monitoring Package is contained in the enlargement of the crate that is on top of the outdoor unit. This crate also contains the refrigerant line set and the low voltage cables used for wiring the thermostat and for wiring the outdoor unit controls.

2. Lower the legs on the outdoor unit to the length that is appropriate for the expected snow cover in your area. Four screws hold each leg, and the legs are pre-drilled for a number of positions; however, you may have to slightly enlarge some of the holes if you're starting new threads with the old sheet metal screws. Set the outdoor unit up on its concrete pad or patio stones to the right height before forming and connecting the line set.

3. The lower compartment of the indoor unit contains the heat pump thermostat and a spare Installation and Service Manual. The upper compartment contains all low voltage and power wiring terminals.

Control Wiring:

4. Use the 8-conductor multi-colour cable for connecting the heat pump to the termostat sub-base. I have handwritten a suggested colour-code on the revised circuit diagram sent to each participating utility contact person earlier. Only 7 out of the 8 wires are used. Take care to form the wires carefully around the terminals at the termostat end. They are very close together and stray strands could easily bridge two screws together.

5. Connections at the heat pump end for the control wiring can use spade lugs or the terminal screws provided. I found that the three spade terminals under each screw left little length under the screw for wrapped connections. Either remove and cut off some of the spade lug terminals, or give up and put spade lugs on all the field wiring! Note that the R1 terminal on the circuit diagram is now divided into two terminals R1a and R1b. They are separately fused, but at the same potential, so please observe the suggested connections to split the load properly. One spare for the chassis-mount (red-top) fuse is taped in

front of the socket in the wiring compartment. This fuse is a special 3.2A model and is the only one that will fit the red socket. The other fuse is an ordinary 3A in-line model, and replacements are readily available.

6. Use the 6-conductor paired cable for the control wiring to the outdoor unit. Take care to keep the pairs together because the black wire in each pair cannot be identified if it is separated from its correct mate. Use the pairs separately to connect 1) the expansion valve, 2) the 24VAC supply to the defrost control, and 3) the two output contacts, COM and NC, on the defrost control. Spade lugs of the proper sizes greatly ease the wiring of the outdoor unit.

7. Three of the control wires from the outdoor unit connect to terminals inside the electronic compartment at the bottom of the wiring compartment. You must remove screws on a metal cover over the electronic board to gain access to the terminal strip for EV, DC1, and DC2. When you replace the metal cover, make sure that it does not contact any components or terminal lugs. I added spacers under this cover to prevent any such contact.

8. Low voltage wiring to the Monitoring Package is all done by means of a plug-in umbilical cable that is permanently attached to the Monitoring board. Locate the board in convenient place for taking readings and plug the control cable into its socket in the lower left corner of the wiring compartment. No special provision has been made for getting this cable out of the wiring compartment. You may be able to fit the plug end through a box connector in the top, or you can easily cut a small exit slot in the lower right corner of the wiring compartment door-ledge. Use a hack-saw to make the 1/2" cut needed, and bend the metal neatly back into the compartment. Tape the cable where it comes through the cut metal and secure it from the heat pump to the Monitoring Package.

Power Wiring:

9. All cable for power wiring must be field supplied: 100-Amp two conductor plus ground for the indoor unit and #14 NMW10 conductor for the outdoor unit's fan. The indoor unit uses no neutral connection.

10. The 100-Amp cable from the power panel goes first to the top lugs of the left-hand meter on the Monitoring Package. When you remove the meter from its base, you will notice a small-guage wire connected to the meter itself. This wire turns each meter on or off at the proper times during the alternate-day experiment. This wire is provided with a wire nut connector for easy removal of the meter during the wiring process. Replace this connection when the meter is ready to be re-installed.

11. It will probably be advantageous to leave the 100-Amp wire from the power panel to the Monitoring Package long enough to reach the heat pump directly at the end of the experiment when the Monitoring Package is removed. If this is not practical, a junction box will be required to join the two cables when the Monitoring Package is removed.

12. The second piece of 100-Amp cable must run from the lower lugs of the right-hand meter on the Monitoring Package to the heat pump itself. Ground the power wiring in each meter-base and at the heat pump lug provided for this purpose.

13. Power wiring to the outdoor unit's fan comes from the terminal block labeled 1-2-3 that is just to the lower left of the main power fuse area in the wiring compartment. Only terminals 1 and 2 are used. Ground this wire to the chassis lugs at both the indoor and outdoor ends of the cable. The outdoor ground screw is under some wires in the outdoor wiring compartment. Access to the outdoor wiring compartment cover is gained by removing the top grill of the outdoor unit.

14. Terminals labeled H1-H2 and AC1-AC2 in the power wiring compartment are intended for switching the supply to a humidifier or air-cleaner respectively. Each set is an isolated contact pair that closes only when the indoor fan in on; thus, these contacts act as a switch, not a power supply, for the separate accessories used. You should put an appropriate warning label on the wiring compartment door if more than one source of supply is used for the heat pump and accessories respectively.

Refrigeration Connections:

15. These fittings must be scrupulously clean and well-oiled before connection. Use three wrenches at once: one to hold the bulkhead connection, one to hold the pipe-side fitting, and one to turn the nut. The indoor end of the line set is provided with pressure taps for checking low and high side pressures. Never leave rubber hose gauge sets connected to a heat pump for long periods of time: rubber hoses often leak! Coil any extra pipe length in a loop or U-bend on the wall or ceiling. The indoor end of the large vapor line is provided with a pre-made 90 degree bend for convenience. Make any other bends carefully with the appropriate tube bending tools only.

16. Proper refrigerant charge is best checked with the unit running in heating mode at moderate outdoor temperatures using the procedure listed under "Checking...", below. There is a chance the unit may be low on charge. Check the newly installed system for leaks at the couplings and make sure that all access fitting caps are tight and leak-free. (Make sure to check both caps on the refrigerant lines and the two in the compressor compartment). Consult the Manual for the correct amount of R22 depending on your line set length. About 11 lbs of charge is needed by the system. About 1 lb of vapor remains in a system that has been discharged to 30 psig pressure (ie: when no liquid remains in the system). This information can be used if you decide to dump and

recharge a system without using a vacuum pump. Of course, if you suspect that system pressure has ever dropped below atmospheric, you will have to evacuate the whole system to remove trapped air.

First Operation:

17. Move the thermostat sub-base fan switch to the ON position and set the speed of the fan using the control knob that is inside the indoor unit's wiring compartment. About 1100 cfm should be maintained for good heating mode efficiency.

18. All power-ups and turn-offs of the heat pump compressor are followed by a 6 minute lock-out cycle. You must wait out whatever portion of this 6 minutes is left before the unit will respond to any thermostat call for heating or cooling. If more than 6 minutes have elapsed since the last turn-off, then the compressor will respond right away. A lock-out cycle can be recognized by the LED pattern given in the Installation and Service Manual.

19. The electronic control on this heat pump sets the opening of the expansion valve by "watching" the refrigerant liquid in the lower part of the condenser (indoor coil). If the level rises too high, more voltage is applied to the valve to open it and let more refrigerant out to the outdoor unit. The micro-computer that does this job has TWO modes of operation. INITIAL PROGRAM mode is set following any power failure to the unit. NORMAL PROGRAM mode is set only after the refrigerant liquid level is seen to go through one complete up and down cycle in the condenser. INITIAL PROGRAM mode can be easily recognized by watching the LED indicator lights on the electronic board. They will flash in railway crossing "wig-wag" fashion on a 1-second time base during the on cycle.

20. Variations between different expansion valves may mean that for some, the INITIAL PROGRAM mode can only handle heating cycle start-ups between about +8C and -14C outdoor temperature (future refinements to the micro-program may eliminate this restriction). If you are beyond either end of this temperature range, you may have to "fool" the unit into the NORMAL PROGRAM mode. If you don't, the heat pump will have a lower output and efficiency than shown in the specifications for the given outdoor conditions. You can recognize a heat pump that is unable to come out of INITIAL PROGRAM mode by the following signs:

    a) The LED's never stop their "wig-wag" flashing, even after an hour of operation.
    b) Suction pressure will not be the proper value (low at high ambients or high at low ambients).
    c) At higher outdoor temperatures, refrigerant rises above the level sensor in the condenser and never comes back down. This is best detected by measuring the AC voltage across "TS", the thermistor sensor, by connecting a DVM to points X1 and RT. Ten volts or so indicates a level above the sensor; three volts indicates below.

d) At cold outdoor temperatures, refrigerant stays below the level sensor and never comes back up (see above voltages).

21. Fooling the micro at higher temperatures is most easily done by blocking part of the outdoor fan discharge to make the unit think it's colder than it really is outside. You may have to turn the unit off, then on again to get the refrigerant level to go down below the sensor (see 20C, above). When the micro jumps to NORMAL PROGRAM mode, the flashing LED's will stop (see I&S Manual).

22. Fooling the micro at very cold temperatures can be easily done by disconnecting the wire to the expansion valve for several minutes or as long as it takes for the refrigerant to rise above the sensor (see 20d above). Then re-connect the expansion valve, and when the micro jumps to NORMAL PROGRAM mode, the flashing LED's will stop (see I&S Manual).

Checking The Refrigerant Charge:

23. I have not been able to successfully reconcile the changing instructions in the Manual using the subcooling band in Figure 1 with my understanding of the way the refrigerant control in this heat pump works. I have found that undercharge can be best detected at moderate outdoor temperatures (10C and above) in heating mode by measuring the temperatures of the liquid and vapor lines leaving and entering the side of the indoor unit. If the liquid (smaller) line is substantially warmer than the vapor line (which should be near outdoor temperature), then the accumulator is "dry" and needs more charge. The heat pump must be in NORMAL PROGRAM mode for this sign to be unambiguous. After adding 1 pound of R22, cycle the unit off and on again to see if the liquid line now stays properly cold. If it doesn't, add another pound and repeat the steps above.

24. This heat pump (like all others) needs more refrigerant at warmer heating temperatures than at colder heating temperatures. Unlike other heat pumps, though, this one can completely compensate for undercharge at low temperatures. So long as enough refrigerant remains in the accumulator to cover the liquid line heat exchanger, NO REDUCTION in performance will be observed. Only as outdoor conditions become warmer is the extra refrigerant from the accumulator needed by the system, and only then will low charge manifest itself as described in paragraph 23 above. Low charge at any given oudoor temperature will always be accompanied by a warming of the liquid line to near room temperature, and a simultaneous lowering of the suction pressure below normal values for that outdoor temperature.

Final Configuration:

25. As noted in the alternate day agreement, the volunteer is requested NOT to use thermostat set-back because it would interfere with the accuracy of the energy measurements. Another aid to accuracy would be if the electric heater banks were closely matched to the requirements of the test house. If all 15.2kW are not needed to meet house heating demand,

then one or two stages can be dropped by either unplugging and taping one or two of the red wires going to the bottom of the 40A fuse blocks in the unit, or one of the 40A fuses can be removed altogether. This would give 7.6kW heating capacity which, surprisingly, is enough for many houses in spite of what the calculations say! Removing only one red wire would give 11.4kW, probably enough for almost any dwelling. Temperature changes will, of course, be gradual under such conditions, but many people prefer this to large overshoots. In any case, without any set-backs, there will be no need for fast recovery rates during the course of the experiment.

26. Set the 24-hour timer by pulling out and rotating the disk to the right time. One or the other light will be on to indicate which heating mode is activated at any given time. The timer toggles this mode every day at about 2PM. Don't bother resetting the time after short power failures, but do so and note it after major outages. Take a set of readings if possible after such a re-set.

27. Air conditioning will only work if the timer toggle is showing the "heat pump" mode light. Wait until a day when it does, then REMOVE one of the small fuses on the side of the monitor box by turning the cover 1/4 turn and pulling the fuse out. This will "freeze" the timer and mode for the summer. Simply lay the fuse aside and put it back in next fall for the heating season. Take some care in removing and replacing this fuse because it is at line voltage. Also, if the timer is between the 2PM on and off lugs, inserting the fuse will toggle the monitoring package back and forth between the two modes. To avoid this, pick a time outside of the 2PM changeover interval.

APPENDIX H

OPERATIONAL CHECKS OF THE CEA/KEEPRITE HEAT PUMP

S. Yap, Ontario Hydro

The seven CEA/Keeprite heat pumps are hand-built prototypes that may suffer from certain assembly defects that are best corrected by carrying out a full operational check after the heat pump goes into service. This monograph outlines the procedure for an operational check.

1. Indoor Air Flow

The blower and motor have been selected to provide an air flow of 1125 cfm across the indoor coil. Air flow can be adjusted by adjusting the indoor fan speed control (FSC) located in the indoor unit electrical box. To check for correct cfm, put the heat pump in the emergency heating mode and carry out an air flow test using the following formula taken from a field practice manual on air conditioning.

$$\text{cfm} = \frac{\text{room sensible heat (btuh)}}{1.08 * (\text{room db} - \text{supply db}) \text{ (F)}}$$

The inlet air and discharge air temperatures can be measured easily using a temperature meter with a probe. Make sure that the discharge temperature is measured far enough downstream of the heaters to minimize the radiation effects of the heaters.

The room sensible heat gain can be determined from the kilowatt-hour meters. The power delivered by the heaters is calculated by taking a stop watch reading of a number of disc rotations.

$$P = \frac{DR * Kh * 3600}{t} \quad \text{(watts)}$$

where:

- DR - number of disc rotations (rev)
- Kh - meter constant (w h/rev)
- t - time in seconds for disc rotations (sec)
- 3600 - convert sec to hour (sec/h)

Once the necessary information has been collected, the cfm can be determined. If the cfm is incorrect, adjust the FSC and repeat the air flow test to get desired cfm. Note that the air flow can vary by 50 cfm or so without significant effects.

2. Outdoor Air Flow

Check the outdoor fan operation for proper air flow. The fan should operate at low speed at warm temperatures (greater than 72F $\pm$ 6F) and on high speed at colder temperatures (lower than 57F $\pm$ 6F). Between these two values the fan may operate at either speed depending on the temperature history of the control.

If the fan speed is incorrect, disconnect main power and remove the top grill and the box cover. Check the wiring to the fan control thermostat (FCT) mounted on the side wall of the outdoor unit. Using a pair of insulated gloves and pliers, remove and switch the red and black wire from the FCT to the fan motor. The change in fan speed is noticeable when power is reapplied.

3. Defrost Sensor

Stop the outdoor fan by shutting off the heat pump. Check the two plastic hoses attached to the defrost sensor. The top nozzle marked "vacuum side" should have the plastic hose extending to the interior of the V-shaped coils. The second hose should be connected to the lower nozzle and extend to the exterior of the V-shaped coils.

A check carried out on a field installed unit revealed an assembly flaw. The plastic hoses were reversed. To correct this assembly flaw, pull the plastic hoses out and switch them. Do not disconnect the hoses at the nozzles as they will be difficult to reconnect. After the switch, make sure that there are no severe constrictions along the length of the hoses.

4. Performance Test

Determine performance by measuring the COP (coefficient of performance). For this, the temperature difference between the return and discharge air, and two power quantities need to be measured.

With the heat pump off, remove the white wire from terminal block #2 to disconnect the second stage. Run the heat pump in the heating mode by setting the thermostat to the far right. Monitor and record the two temperatures after they have stabilize. Also record the heat pump electrical power input from the disc rotations of the kilowatt-hour meters. Next, shut down the heat pump and reconnect the white wire. Put the thermostat in the emergency heating mode. Allow the temperatures to stabilize and record the temperature difference and the power input/output of the electric heaters. The electric heaters are 100% efficient.

The COP is calculated as follows:

First, estimate the thermal output of the heat pump in the heating mode.

$$\text{HP Thermal Output} = \frac{\text{temp diff HP mode}}{\text{temp diff emergency heat mode}} \times \text{Electric Heater Power Output}$$

Second, calculate COP using the following formula:

$$\text{COP} = \frac{\text{Thermal Output of Heat Pump}}{\text{Electrical Input of Heat Pump}}$$

Compare this COP to the performance data in the Installation and Service Manual. If the measured COP is low, check the refrigerant charge as outlined in D. Young's report on "Tips for installing the Keeprite/CEA Cold Climate Heat Pump" (Appendix G). The heat pump is most likely low on charge.

5. Equipment Required for Operational Check

These checks will normally require a day or two to complete. Some equipment is required. At least two temperature meters with digital displays to 1 decimal point is recommended. Extra refrigerant, weigh scale and an assortment of hand tools are useful to take along.

Dr. L.F. Monier	Hydro Quebec 75 Dorchester Blvd. W., 6th Floor Montreal, Quebec H2Z 1A4
Mr. V.L. Powell	TransAlta Utilities Corporation P.O. Box 1900 110-12th Avenue S.W. Calgary, Alberta T2P 2M1
Mr. A.F. Baljet	Electrical Research
Mr. J.M. Bell	Electrical Research
Mr. D.J. Young	Electrical Research
Mr. D.F. Cuthbert	Electrical Research
Mr. F.J. Lenarduzzi	Electrical Research
Mr. S. Yap (5)	Electrical Research

Public Reference Centre
Editorial Section (2)
Office Copies (2)
Extra Copies (3)
Section File (3), KR263

DISTRIBUTION

Dr. D. Mills	Director of Research, KR116
Mr. L.G. McConnell	Vice-President of Corporate Planning, H05A27
Mr. D.B. MacCarthy	Vice-President of Energy Management, C27A1
Mr. D.G. Comissiong	Director of Marketing Operations, C26A1
Mr. G.F. McIntyre	Director of Marketing Services & Development, C25A6
Mr. B.J. Conway	Marketing Services & Development, C24A6
Mr. J.E. Mitchell	Marketing Services & Development, C25F6
Mr. E.R. Kulperger	Marketing Services & Development, C25C6
Mr. L.D. Wilson	Marketing Services & Development, C25A01
Mr. M.J. McGee	Marketing Operations, C26A2
Mr. G.T. Martin	Marketing Operations, C26E6
Mr. B.L. Killins	Marketing Operations, C26F5
Ms. K.A. Wagner	Marketing Operations, C26F06
Mr. D.T. Peters	Marketing Operations, C26F3
Mr. C. Jen	Marketing Operations, C26E5
Mr. S. Mastoris	System Planning, H4D12
Mr. G.R. McBrien	Central Region
Mr. W.M. Hale	Eastern Region
Mr. D.E. Shipston	Georgian Bay Region
Mr. J.R. Mason	Northeastern Region
Mr. J.M. Tarling	Northwestern Region
Mr. D.L. Eamer	Western Region
Mr. H.E. Douglas	Canadian Electrical Association 1 Westmount Square, Suite 500 Montreal, Quebec H3Z 2P9
Dr. P. Critchlow	IREQ 1800 Montee Ste-Julie Varennes, Quebec J0L 2P0
Ms. M. Yu	Saskatchewan Power Corporation 2025 Victoria Avenue Regina, Saskatchewan S4P 0S1
Mr. R.V. Smith	Central Hudson Gas and Electric 284 South Avenue Poughkeepsie, NY 12601-4879
Mr. J.C. Fraser	Nova Scotia Power Corporation Box 910, Scotia Sq. Duke Tower Halifax, NS B3J 2W5
Mr. L. Baraniuk	Manitoba Hydro 820 Taylor Avenue Winnipeg, Manitoba R3C 2P4
Mr. W. Gillard	Saskatchewan Power Corporation 2025 Victoria Avenue Regina, Saskatchewan S4P 0S1
Mr. D. Henriques	B.C. Hydro 970 Burrard Street Vancouver, B.C. V6Z 1Y3
Mr. R. Little	N.B. Electric Power Commission 527 King Street Fredericton, N.B. E3B 4X1